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VISCOELASTIC EVALUATION OF BIOLOGICAL SOFT TISSUE IN CRUSH PROCESS AT SUBSONIC LEVEL FOR ANTI-BIRD STRIKE TECHNOLOGY OF AIRPLANE

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Abstract. Miniaturization and lightening of airplane are advanced to improve its economic efficiency, and the safety technology of airplane design becomes difficult while the accident of bird-strike is increasing year by year. Then a system of shock impact test by using airsoft rifle is developed to evaluate the design technology of anti-bird strike structure of airplane. The viscoelastic characteristics of specimen is evaluated by analyzing stress response using the modified Hertz contact theory and the wave equation at the moment when simple ball bullet is shot to specimen by the airsoft rifle. In the results of experiment, the obvious relationship is observed subjectively between quasi-static and impact responses of specimen. The evaluated viscoelastic relationship is applied to simulate the impact test by using LS-DYNA with fundamental viscoelastic constitutive equation and the material parameters derived from the impact test, and the well similar behavior has been simulated by the constitutive equation. By using the developed technology here, the phantom imitating real bird will be developed as standard specimen for an anti-bird strike test in future.

1 INTRODUCTION

While the accident of bird strike is increasing year by year [1], miniaturization and lightening are advanced in order to improve economic efficiency, and the technology of safety design of the airplane becomes difficult. Then system of shock impact test by using airsoft rifle is developed to evaluate the design technology of anti-bird strike structure of airplane. Simple ball bullet is shot to specimen in the test by the airsoft rifle and stress response in load cell of the test system is evaluated by the modified Hertz contact theory and the wave equation which are used to analyse the viscoelastic characteristics of the specimen. In the results of experiment, the obvious relationship between quasi-static and impact responses of specimen is observed subjectively, and the effect of hardening by the impact is obvious in the results of muscles of chicken. The evaluated viscoelastic relationship is applied to simulate the impact test by using LS-DYNA with fundamental viscoelastic constitutive equation and the material parameters derived from the impact test, and the well similar behaviour has been simulated by the constitutive equation. By using the developed technology here, the phantom imitating real bird will be developed as standard specimen for an anti-bird strike test in future.

2 EXPERIMENTAL SYSTEM

2.1 Impact Test by Ball Collision

In order to evaluate the deformation behavior of material at subsonic level, the impact system using resin ball bullet is adopted on the development of an impact test by using air gun. The developed system is shown in Figure 1 with other measurement instruments for the evaluation. The air gun used in this system is one of air soft gun (toy gun) made by Tokyo Marui Co., Ltd., Japan. The type M14 of the toy gun is adopted because it has the capability to shoot a ball bullet at 100 m/s. The shot bullet collides with specimen on a load cell, and causes stress waves in the cell. Furthermore, the wave in load cell is measured by strain gage pasted on the side of the cell, and logged through AD board by PC. Furthermore, the wave in load cell is measured by strain gage pasted on the side of the cell, and then is logged by PC. The situation of the collision is observed also with a high speed camera.

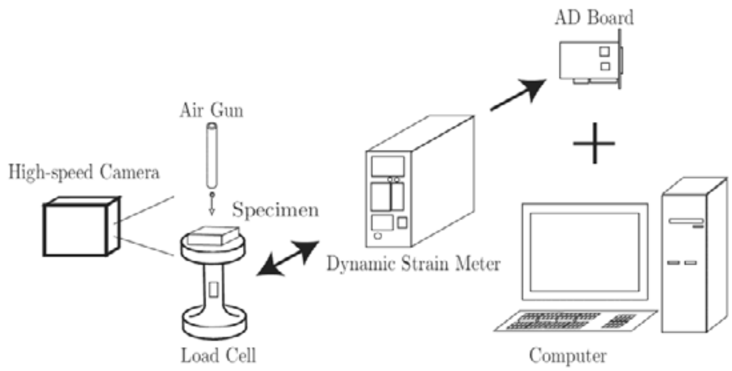

Figure 1: Page layout

2.2 Evaluation Procedure of Deformation Characteristics of Materials

The famous Hertzian contact stress theory [2] is expanded to evaluate the collision behavior of the impact test system. The fundamental form of the theory can be written in following form as the relationship between contact force F and indentation depth d for the contact problem of rigid ball and elastic body with plane surface. The fundamental form of the theory can be written in following form as the relationship between contact force F and indentation depth δ of rigid ball on the contact problem of elastic plain body:

$$F = \frac{4}{3}\frac{E}{1-\nu^2}\left(\frac{\phi}{2}\right)^{\frac{1}{2}}\delta^{\frac{3}{2}} = A\delta^{\frac{3}{2}} \tag{1}$$

Here, variable E, ν and ϕ indicate Young's modulus, Poisson's ratio and the diameter of the ball indenter.

Equation (1) is the theoretical solution for semi-infinite elastic body, but specimen on the load cell in Figure 1 should have finite body because of the measurement of stress wave. Then the expanded relationship [3]-[4] of Hertzian contact stress theory is adopted to analyze the contact problem of finite elastic body. The expanded Hertzian contact stress theory has the following form with thickness coefficient B:

$$\hat{F} = \frac{4}{3}\frac{E}{1-\nu^2}\left(\frac{\phi}{2}\right)^{\frac{1}{2}}\{\delta(1+B\delta)\}^{\frac{3}{2}} = A\{(1+B\delta)\delta\}^{\frac{3}{2}} \tag{2}$$

The contact force $\hat{F}$ at specimen on the load cell causes stress wave into the cell and propagate to the bottom of it. The propagation can be represented by wave equation (3) with the constant c as the function of time t and the position x as follows:

$$\frac{\partial^2 u}{\partial t^2} = c^2\frac{\partial^2 u}{\partial x^2} \tag{3}$$

By using Equation (2) as a boundary condition of the wave equation (3), the solution $u(x, t)$ can be derived with some constant a, b and c as follows:

$$\begin{aligned} u(x,t) = a\{&3\log\{\sqrt{1+b(ct-x)}+\sqrt{b(ct-x)}\} \\ &+\sqrt{b(ct-x)\{1+b(ct-x)\}} \\ &\{16b^3(ct-x)^3+24b^2(ct-x)^2+2b(ct-x)-3\}\} \end{aligned} \tag{4}$$

This equation (4) can be used to analyze the wave profile in the cell for the mechanical evaluation of the specimen on the cell. In this paper, a coefficient D is used to represent the deformation behavior of the specimen. This coefficient D is defined as follows by the definition of Hooke's law with the consideration of viscous effect, and is called deformation resistant modulus in this paper:

$$D = \frac{3}{4}A(1-\nu^2)\left(\frac{\phi}{2}\right)^{-\frac{1}{2}} \tag{5}$$

3 EXPERIMENTAL RESULTS AND NUMERICAL SIMULATION

In Figure 2, the experimental results measured by the system shown in Figure 1 are shown as example. Here, 4 materials are indicated: chicken breast, water, 25% gelatin and 13% gelatin. Every materials show the impact crown at moment of ball collision, but their shapes are different and it indicates that the deformation characteristics of the materials are different among them.

This difference is analyzed by the relationship shown in section 2.2. And the analyzed result is applied to deformation analysis using LS-DYNA by using the evaluated results of the materials. In this analysis, the constitutive equation of Hermann and Peterson [5] is adopted to represent the viscous effect of the materials. The equation has the definition among

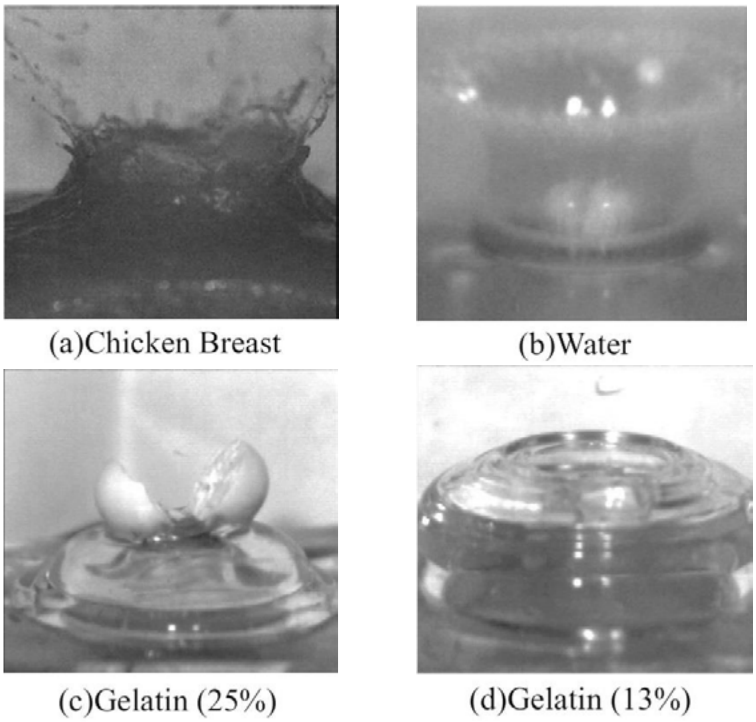

Figure 2: Page layout

short-run elasticity G_0, long-run elasticity G_∞, and viscous coefficient b for the representation of shear elasticity $G(t)$ as shown in equation (6). Then the normal elasticity $D(t)$ is defined for the application of equation (5) in this paper:

$$G(t) = G_\infty + (G_0 - G_\infty)\, e^{-\beta t} \tag{6}$$

$$D(t) = D_\infty + (D_0 - D_\infty)\, e^{-\beta t} \tag{7}$$

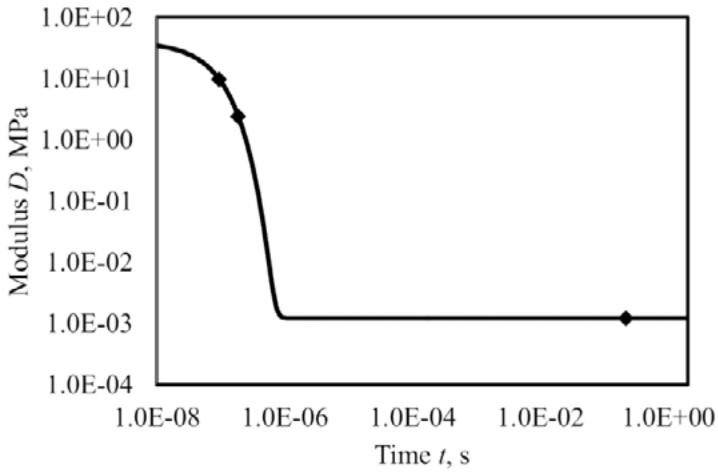

Figure 3: Page layout

By using the equation (7), the relationship of Hermann and Peterson is defined with some experimental results shown Figure 3. The defined relationship can be applied to the simulation using LS-DYNA, and impact test by ball collision is simulated as shown in Figure 4. In this simulated results, the similar shape of impact crown shown in Figure 2 is computed by using the evaluated result.

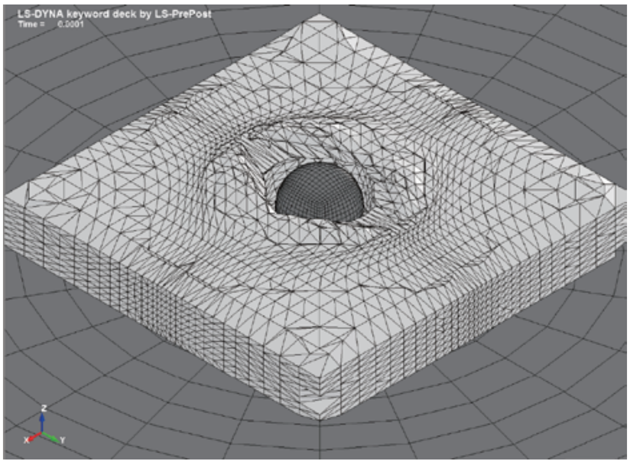

Figure 4: Page layout

4 CONCLUSIONS

- The system of impact test by ball collision is introduced for the evaluation of collision mechanics on bird strike. Many problems of bird strike will be analyzed by using this result from now on.

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